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Behrens, Jane; Gräns, A.; Andersen, Niels Gerner; Neuenfeldt, Stefan; Axelsson, M.

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Recovery of gastric evacuation rate in Atlantic cod *Gadus morhua* L surgically implanted with a dummy telemetry device

J W Behrens[1*], A Gräns[2], N G Andersen[3], S Neuenfeldt[1] and M Axelsson[2]

[1]Technical University of Denmark, National Institute of Aquatic Resources, Kavalergaarden 6, DK-2920 Charlottenlund, Denmark, [2]University of Gothenburg, Department of Zoology, P.O. Box 463, 405 30 Gothenburg, Sweden, and [3]Technical University of Denmark, National Institute of Aquatic Resources, North Sea Science Park, P. O. Box 101, DK-9850 Hirtshals, Denmark

*Corresponding author. Tel + 45 21314776; fax +45 3396 3333; email: jabeh@aqua.dtu.dk

Short title Gastric evacuation in surgically implanted cod

Abstract

The current study investigated how the gastric evacuation rate (GER) was affected after surgically introducing dummies of a blood-flow biotelemetry system into the abdominal cavity of Atlantic cod *Gadus morhua*. Gastric evacuation experiments were performed two and ten days post surgery on surgically implanted and control *G. morhua* force-fed sandeel *Ammodytes tobianus*. The results were compared with previously obtained estimates from unstressed conspecifics voluntarily feeding on a similar diet. After two days, GER was significantly lower in the group of fish with the dummy implants compared to the control group, but following ten days of recovery no significant difference was seen between the two groups. The difference between implanted and control fish observed 2 days post surgery may have arrived either from surgery, post-surgical stress and/or the presence of the implant. The conclusion is that 10 days of postsurgical recovery will stabilize GER in *G. morhua*, thus indicating that at this point the implant *per se* did not affect GER. Both the fish with surgical implants and controls in this study evacuated their stomachs much slower and with much higher inter-individual variation compared to *G. morhua* feeding voluntarily on similar prey items.[1] The lower GER and higher inter-individual variation for force-fed fish indicates that handling, anaesthetization and force-feeding impair GER and that individual fish respond differently to the suppressing effects.

Keywords Post-surgical recovery, gastric evacuation, *G. morhua*, implant, biotelemetry

Invasive procedures are often necessary for the physiologist to understand the mechanisms behind various physiological parameters. In fish, measurements of cardiovascular parameters such as blood flow and blood pressure involve handling, anaesthesia and surgical implantation of catheters and flow probes in and around vessels and sutures to close the incisions. In traditional laboratory experiments, standard bench top blood pressure and blood flow measuring units are used, which means that the animals are 'hardwired' to the equipment during the experiments. Catheters and leads from flow probes penetrate the body wall and increase the risk of infection. Furthermore, to prevent tangling and ripping of wires the animals are most often confined in small containers, which severely limits the range over which they can move with the risk of introducing confinement stress. The animals are usually left for 18 to 48 hr before experimentation is initiated, the main reason for such shorts periods being the high risk of infection after an extensive surgery.[2] In cases where catheters are used, limits on the time where these will remain open may also be decisive. However, unless appropriate recovery time is ensured following surgical procedures and instrumentation major concerns are the validity of data and ethical considerations. In a study on rainbow trout *Oncorhynchus mykiss* using bioelectric potential recordings to measure heart rate, fH, (i.e. a non-invasive method) the fish were handled and then left to recover for at least 3 days where after their basal heart rates were much lower than those presented in previous studies using traditional methods involving surgical procedures.[3] A lower heart rate usually is indicative of lower stress levels pointing to that these animals were not as stressed due to confinement and the use of 'hardwired' techniques. Obviously, any misinterpretation of data may have important consequences for our understanding of the physiology of fishes and researchers should be encouraged to seek refinements of techniques to ensure more valid results as well as better animal welfare.

The rapid development of telemetric devices opens new research areas that have not been possible with hardwired animals and during the last few decades there have been great advancements made in applications of biotelemetry in fish physiology. Biotelemetry allows data collection from specimens that move around freely and can behave in a more natural way. In the telemetrically instrumented animal the risk of infections is lower since there are no skin-penetrating wires. Furthermore long term recovery- and recording periods are possible reducing stress from handling, making this an attractive alternative. Altogether, this provides a number of welfare advantages and the opportunity to obtain higher quality of the measured variables and more reliable routine values. A recent study on white sturgeon (*Acipenser transmontanus*) showed that routine heart rate of freely moving biotelemetric instrumented fish was lower compared with hardwired, confined conspecifics as well as with previous values reported for white sturgeon.[4, 5] The downside is that the animals are carrying the entire recording/transmitting unit, increasing their body mass and possibly impairing the capacity to generate thrust by altering the ability to bend the body. It may furthermore interfere with the internal organs if placed in the body cavity. Nevertheless, a fully implantable system maximizes the likelihood that the studied fish will be treated normally by surrounding fish[6] and minimizes the risk of infection and expulsion.[7] Even the presence of a small, protruding antenna has been shown to cause adverse tissue reaction at the antenna exit[8, 9] and to elicit aggressive attacks from other individuals of Atlantic salmon smolts.[6]

We are looking to use a fully implantable biotelemetry system [5,10,] to study blood flow distribution in Atlantic cod *Gadus morhua* L. voluntarily feeding and moving between different habitats. Before employment of such a system it is, however, imperative to evaluate appropriate post-surgery recovery time and possible adverse effect of the telemetric implant. Using a dummy version of the dual blood flow biotelemetric system used by Gräns and co-workers,[5, 10] the aim of the present

study was to examine the effects on the gastric evacuation rate (GER) of handling, surgery and instrumentation of *G. morhua* with a dual channel blood flow telemetric system following short term (two days post surgery) as well as prolonged (ten days post surgery) recovery. Both the surgically implanted and control fish were force-fed in order to standardize the amount of food and the time of feeding. The ability to evacuate the force-fed meal was determined and compared with estimates obtained from unstressed conspecifics that fed voluntarily.

Materials and methods

Fish

Wild *G. morhua* ranging in total body mass from 290 to 815 g were caught in late 2009 by fyke net in the vicinity of the Marine Biological Laboratory in the northern part of Øresund, Denmark. The fish were transferred to the laboratory where they were kept in 9-10 °C re-circulated, aerated seawater. The tank was covered by tarpaulin to avoid unnecessary disturbance of the fish. Light/dark conditions were 16h: 8h. All fish were acclimated to laboratory conditions for a minimum of 12 weeks before experiments were initiated and fed *ad libitum* three times a week with chopped herring *Clupea harengus* L. or Raitt's sandeel *Ammodytes marinus* Raitt. Before the experiment the fish were starved for five days to ensure that their stomachs were empty.

Preoperative care

Individual *G. morhua* was anaesthetized in 15 l of water containing 0.15 g l^{-1} 3-aminobenzoicacid ethyl ester (MS-222) until gill ventilation ceased. Each fish was weighed and length measured before it was positioned with the ventral side facing up on an operating table covered with wet sponges. Anaesthesia was maintained during the surgery by pumping oxygenated sea water

containing MS-222 (0.075 g l^{-1}) over the gills. All surgical instruments, the dummy implant and associated leads were sterilized by the use of a cold steriliant (Cidex, Johnson & Johnson Company, USA).

Dummy implant

Our long-term goal is to implement the fully implantable biotelemetry system used by Gräns et al.[5, 10] This system weighs 35g (total mass of implant and battery) in air and we aim for a transmitter:fish mass ratio of 3-4%. Consequently, the dummy implant was constructed so that its total mass equaled 19 g in air, thus, corresponding to an average of 3.7 (0.3) % of the mean body mass of the present experimental *G. morhua*. It was made of silicon-coated stainless steel (L = 35 mm, H = 5 mm, W = 16 mm) with an attached silicon-coated dummy battery made of plastic tubes (L = 18 mm, D = 11 mm) and two silicon leads with a probe cuff each, and the implant fitted easily within the abdominal cavity of the fish.

Surgery

The splanchnic circulation in *G. morhua* is derived from the celiacomesenteric artery (CoMe). The CoMe is the largest single branch of the dorsal aorta and branches to form the celiac artery and mesenteric artery. The celiac artery supplies parts of the cardiac stomach, the pyloric stomach, the proximal intestine and parts of the distal intestine, while the mesenteric artery supplies the remainder of the gastrointestinal system, the gallbladder and the spleen.[11] The surgical procedures were performed on 10 fish [body mass 550 (144) g and length 38.7 (3.2) cm] and done in accordance with the guidelines described in permission 2010/561-1812 from the Danish Ministry of Justice. For placement of the first dummy probe, a 2-cm-long incision was made

alongside the basibranchiale bone left of the midline, and the liver carefully retracted, where after the CoMe artery was exposed and cleared. The dummy implant and battery were then carefully placed in the abdominal cavity and the retracted organs restored to their places of origin. Furthermore, an individual PIT tag (12×2 mm, ISO standard 11784/11785, FDX-B) was placed in the body cavity for later identification of the fish. To access the ventral aorta for placing the second dummy probe, a 0.5-cm ventral incision was made posterior to the gill juncture and carefully, without disrupting the pericardium or damaging any vessels, the dermal and sub-dermal musculature and connective tissue were separated using blunt dissection tools to expose the ventral aorta. The probe was tunneled under the skin from the abdominal cavity to the incision above the ventral aorta (see Figure 1 for schematic overview of positioning of the system). The wires from the probes were anchored with a single stitch of 3/0 silk suture in the sub-dermal muscle tissue and the two incisions were closed using sterile monofilament prolene 3-0 suture. Subsequently the cod was given a subcutaneous injection of 0.4 mg/kg [1 M] butorphanol (Torbugesic , Fort Dodge, Iowa, USA) for postoperative pain relief in addition to an injection with 10 mg/kg [1 M] Enrofloxacin (Baytrilo, Bayer, USA) antibiotics, to minimize the risk of infection. Finally, to reduce incidence of oomycete infections povidone iodine powder was applied to the closed incision before returning the fish to recovery water. The surgical procedure including anaesthesia and awakening took approximately 20 min for each fish and when ventilation and locomotion had been reestablished, the fish were returned to their home tank. All but one fish survived the surgery.

The control fish [n=8, body mass 518 (155) g and length 37.1 (2.7) cm] were anaesthetized as described above, and subsequently weighed, length measured and individually PIT tagged. The

tags were placed in the abdominal cavity, using a syringe implanter, taking care not to harm any organs. The control fish were likewise left to recover before being returned to their home tank.

Food

A. marinus constitutes a natural and large part of the diet of wild *G. morhua* and one specimen per cod was used as the experimental meal. To minimize variation in size and condition, specimens of *A. marinus* from a single commercial batch (TripleNine, Hvide Sande, Denmark) were used for force-feeding. The energy density of these prey fish was determined by bomb calorimetry [IKA C-7000 bomb calorimeter (www.ika.net)] on a representative sample after drying it at 60° C until constant mass according to the procedure described in Pedersen & Hislop.[12]

Gastric evacuation experiments

The first experiment was initiated 48 hr post surgery. On the day of experiment, *A. marinus* were quickly thawed in running water, and those of similar total lengths were selected. These were subsequently dabbed dry with paper towel and weighed, and individuals within a mass range of 9.4-15.7 g were chosen (corresponding to 2-3% of the body mass of the *G. morhua*). This food ration was chosen from the largest daily feeding rates observed in wild *G. morhua*.[13] In random order individual cod were anaesthetized by placing them in 15 l of water containing 0.07 g l^{-1} MS-222. They were then force-fed by gently pushing a whole *A. marinus*, bend on the middle, through the esophagus and into the stomach. Immediately thereafter the fish were returned first to recovery water and subsequently to their home tank. The exact time of force-feeding was noted for each fish, as was the length and mass of the prey.

Stomach contents were recovered 22 to 26 hr post force-feeding by stomach flushing following anaesthetization (0.07 g l^{-1} MS-222). The stomach content from each fish was collected on a filter with mesh-size 200 µm, and gently patted with a moist paper towel and weighed. The exact time for recovery of stomach content was noted for each cod.

The fish were subsequently left to recover for 7 days in their home tank where after the above described protocol was repeated in a second trial.

Calculations and statistical analyses

In accordance with the cylinder model of Andersen & Beyer,[14] the gastric evacuation rate of stomach contents in *G. morhua* (as well as in a variety of other piscivorous fishes) can be described independently of meal size by the current mass of stomach contents S_t (g) together with the rate parameter ρ:

$$\frac{dS_t}{dt} = -\rho\sqrt{S_t} \qquad (1)$$

Integrated from time 0 of force-feeding to time t (h) of recovery of stomach contents, the solution to equation (1) is *G. morhua* evacuating its stomach contents according to the relationship

$$\sqrt{S_t} = \sqrt{S_0} - \frac{1}{2}\rho\, t\,; \qquad 0 \le t \le t_{end} = 2\rho^{-1}\sqrt{S_0} \qquad (2)$$

where t_{end} is the time for complete evacuation of the prey.

The ability to evacuate the stomach contents is then described by ρ, which can be calculated for each individual *G. morhua* by reorganization of equation (2):

$$\rho = 2(\sqrt{S_0} - \sqrt{S_t})t^{-1} \quad (3)$$

The rate parameter ρ depends on predator (total) length L (cm), temperature T (°C) and prey energy density E (kJ g^{-1}). The effects of these variables were estimated by Andersen (2001) for different gadoids fed fish prey, and the following relationship was obtained:

$$\rho = \rho_{LTE} L^{1.44} e^{0.078T} E^{-0.86} \quad (4)$$

The basic rate parameter ρ_{LTE} specifies the general ability of the predator to digest and evacuate a specific prey type from the stomach (or reversed: it indicates the resistance of the specific prey to the digestive processes in the stomach). The value 0.00142 ± 0.00011 (estimate ± S.D.) of ρ_{LTE} was obtained from an experiment by Andersen[1] on *G. morhua* that fed voluntarily on lesser sandeel *Ammodytes tobianus* L. The temperature (10.3° C) and mean body size of *G. morhua* (41 cm; 664 g) were similar to those of the present study. This value of ρ_{LTE} was used to decide the evacuation time t of c. 24 h employed in this study, which is shorter than t_{end} and yet long enough to ensure that a significant part of the meal was evacuated from the stomach prior to recovery of the remains.

G. morhua used in the present study varied to some extent in size (Table 1). ρ_{LTE} was therefore used to represent the ability of individual *G. morhua* to evacuate their force-fed meals of *A. marinus*. By use of this parameter, the results could further be compared directly with the above

estimate obtained from unstressed *G. morhua* that fed voluntarily. Combining equations (3) and (4), the value of ρ_{LTE} for each individual *G. morhua* was so calculated by

$$\rho_{LTE} = 2(\sqrt{S_0} - \sqrt{S_t})\, t^{-1} L^{-1.44} e^{-0.078\,T} E^{0.86} \quad (5)$$

Assuming a *G. morhua* to operate with its individual value, the basic rate parameter ρ_{LTE} can be considered the outcome of a normally distributed stochastic variable.[14] Then, the performance of two groups of *G. morhua* with regard to gastric evacuation rate can be compared statistically by use of a *t*-test to the values of this parameter calculated for each *G. morhua* according to equation (5). Before *t*-tests were performed (SigmaStat version 3.5) the assumptions of normality (Kolmogorov-Smirnov test) and homogeneous variance of data (Bartlett's test) were tested. Significance was accepted at $P < 0.05$.

CV of ρ_{LTE} is constant and does not depend on the value of this parameter[15]. According to Sokal & Rohlf[16], this implies that the variances of two values of ln ρ_{LTE} are identical, and that a test of equality of two values of CV is equivalent to *H*-test of equality of the variances of the logarithmic transforms of ρ_{LTE}. The latter was therefore used here to test for equality of CV obtained from the different treatments of fish. Significance was accepted at $P < 0.05$.

Results

Short term recovery (two days)

Two days post surgery, evacuation of force-fed sandeel was considerable slower in fish with surgical implants compared with control fish. The calculated gastric evacuation rate parameter ρ_{LTE}

was thus significantly lower ($P < 0.001$) in implanted *G. morhua* compared to the control, being respectively 4.2×10^{-4} (1.2×10^{-4}) and 9.3×10^{-4} (1.9×10^{-4}) (mean [SD]) (Figure 2). Because the effects of fish length were accounted for by ρ_{LTE} (eq. 5), while temperature end energy density of the prey were similar for all animals (Table I), the observed difference in gastric evacuation rates can be attributed to pure physiological causes. When comparing our data with the value of $\rho_{LTE} = 14.2\times10^{-4}$ (1.1×10^{-4}) obtained in the study by Andersen[1] on *G. morhua* feeding voluntarily on *A. tobianus* (i.e. involving no handling or anaesthesia priory to recovery of the stomach contents) the present gastric evacuation rates only constituted approximately one third (fish with implants) and two thirds (control) of this rate (Figure 2), i.e. both being significantly lower ($P < 0.001$). This difference was also reflected in that on average only 21 and 42% (instrumented and control fish, respectively) of the meals had been evacuated 25 h post force-feeding, which is inefficient compared to the prediction[1] that 62% of the meal should be evacuated.

According to Andersen & Beyer[15] the coefficient of variation (CV) of the basic rate parameter ρ_{LTE} is constant (i.e. independent of the estimated value of this rate parameter). CV should therefore be used when comparing the *variability* of ρ_{LTE} in the different groups of *G. morhua*. For the two groups of force-fed *G. morhua*, CVs of 0.21 and 0.29 (controls and operated, respectively) were significantly ly higher ($P<0.002$ and $P<0.001$, respectively) than the value of 0.08 obtained from *G. morhua* that fed voluntarily[1] (Table II).

Prolonged recovery (ten days)

Ten days post surgery, there was no significant difference ($P = 0.878$) between the rate at which animals with implants evacuated their meal compared to control fish (Figure 2). These estimates of ρ_{LTE} were however still significantly lower (7.7×10^{-4} [1.9×10^{-4}] for implanted and 7.9×10^{-4}

[2.8×10^{-4}] for controls) than the value of 14.2×10^{-4} (1.1×10^{-4}) obtained from *G. morhua* feeding voluntarily on *Ammodytes spp.* ($P< 0.001$).[1] Again, as described above for *G. morhua* 2 days post recovery, the coefficients of variation in both of our groups of fish were significantly higher ($P<0.001$) being 0.24 in surgically implanted fish and 0.35 in the control group (Table II) compared to the value of 0.08 obtained from *G. morhua* that fed voluntarily. In contrast to the improved evacuation ability of the surgically implanted *G. morhua* following prolonged recovery, the percentage of food that had been evacuated by control *G. morhua* at *c.* 23h post force-feeding (36%) was comparable both to the week earlier (43% *c*. 25 h post force-feeding after two days of recovery) and to the value for the surgically instrumented fish (36% *c*. 23 h post force-feeding).

Discussion The present study demonstrates that following two days of post-surgical recovery after introduction of a dummy implant into the body cavity, *G. morhua* is not capable of evacuating a meal at a rate similar to non-operated fish. By using ρ_{LTE} (eq. 5) to compare gastric performance between groups of fish we have accounted for the effects of fish length, while temperature and energy density of the prey were similar for all animals (Table I). Our results thus suggest that the observed difference in GER can be attributed to pure physiological causes derived either from surgery, post-surgical stress and/or the presence of the implant. But following ten days of recovery the suppressing effects on gastric performance caused by surgical implantation was gone. Thus at this stage the presence of neither the implant *per se* nor the surgery was limiting the GER. Reduced post-surgical gastric performance has been reported previously. Twenty-four to thirty-six hr subsequent to invasive surgery sea bass *Dicentrarchus labrax* L. showed a significantly higher gastric evacuation time (GET) [the relationship between GET and GER can be deduced from equation (3)] compared to controls, with stomach contents still above 60%

289 of the initial 24 hr post force-feeding, whereas control animals at this time had less than one third
290 of the meal remaining in the stomach.[17] This is thus in accordance with our results showing that
291 GER had not stabilized in *G morhua* two days post surgery.
292
293 A factor that may affect the recovery and even long term function is the effect on buoyancy. A fish
294 with an implant has to counteract the downward force exerted by the added mass which can be
295 done by secretion of gasses into the swimbladder.[18, 19] With the present implant in the body
296 cavity, a fish, irrespectively of its size, would have to increase its swimbladder volume (5% of the
297 total volume in *G. morhua*[18]) with 14.2 cm^3 of air to become neutrally buoyant. In the smallest *G.*
298 *morhua* this implies an almost doubling of swimbladder volume, which may approach the limit for
299 their capabilities.[20] Swimbladder adjustment is a low cost solution but is slow (up to a day or
300 two)[21, 22] and meanwhile compensation must occur through active swimming which is
301 energetically expensive.[19, 23] Such excess energy use will reduce the aerobic scope available for
302 other processes[24] and this may be part of the explanation for the lower gastric performance
303 observed two days post surgery. Furthermore, active swimming may result in blood being shunted
304 away from the stomach region to prioritize oxygen delivery to the working muscle. [25, 26]
305
306 The use of biotelemetry devices allows experimenters to provide their animals with long
307 recoveryperiods to facilitate complete recovery from instrumentation procedures. Nonetheless,
308 for biotelemetry systems to hold their true/full potential it is imperative that the fish is capable of
309 dealing with not only the effects arising from anaesthesia, handling and surgical intervention but
310 also any potential disadvantages related to carrying the entire recording/transmitting unit. Taken
311 together, our results show that a potential for returning to pre-surgical levels indeed exists, as GER

was stabilized 10 days post surgery in fish carrying the implant in the body cavity. Thus the presence of the implant *per se* did not seem to affect the average gastric performance at this point. The fish in the present study weighed between 290 and 815g resulting in transmitter:fish mass ratios from 2.3 to 6.5%. It has been suggested that the mass of telemetry tags should not exceed 2% of body mass[24, 27]. Several experiments (including experiments on cod) using tags larger than this have however found no significant effect on the swimming performance[29, 30]. We found no correlation between GER and body mass indicating that cod can recover from carrying tags that represent up to 6.5% of the body mass. Along the same lines results from salmonids on recovery of swimming performance following surgical implantation of telemetry devices have shown that Juvenile Chinook salmon *Oncorhynchus tshawytscha* (Walbaum) had a significantly lower critical swimming speed 1 day post surgery compared to controls, whereas full recovery was accomplished after 21 days (in-between evaluations are lacking);[21] Although full recovery was not established, the swimming performance of tagged juvenile *Salmo salar* L. had improved 7 days post tagging at termination of the experiment.[30] Suggestively the fish may either have recovered in the long term, or the tags, representing on average 8.5% of the fishmass, may have been too heavy or have reduced the mobility of the fish.

When comparing the variability in gastric performance between different groups of *G. morhua* the coefficient of variation, CV, of the basic rate parameter ρ_{LTE} should be used (for further details on this see Materials and methods). The value 0.080 of CV estimated from the voluntarily feeding fish by Andersen[1] (Table II) compared well with the estimate of 0.098 obtained from a variety of predatory gadoids and their fish prey.[15] This variation probably reflects the inter-individual variation in gastric performance. Substantially higher values of CV were obtained from both

groups of force-fed *G. morhua*, which may then be explained by an additional variability due to the suppressing effects of handling, anaesthetization and force-feeding on GER to which the individual fish responds differently. An alike large variability has been observed in *O. mykiss*; the lag phase from force feeding until the stomach started to empty varied between zero and 5h.[31] As anticipated, for the present *G. morhua* this furthermore resulted in on average 30% lower values of ρ_{LTE} from control fish compared to the voluntarily feeding *G. morhua* in the study by Andersen[1]. Studies on cod using intragastric transmitters have shown that if the fish voluntarily ingest the baited transmitter (in this case a transmitter wrapped in a fillet of herring) high food consumption rates are maintained in the days subsequent to tagging, in contrast to fish tagged by forced insertion (involving handling and anaesthesia) where food intake was notably lower for up to 15 days post tagging.[32] This indicate that appetite prevails despite the presence of a transmitter as long as handling and anaesthesia is avoided.

To omit interference from anaesthesia and handling in future studies, one important unanswered question to investigate is thus how long it takes for instrumented fish to commerce voluntarily feeding following the surgical procedure.

Although the primary intention of this study was not to focus on wound healing, this is an important matter, not only for ethical considerations but also because biotelemetric methods enable long-term measurements where open incisions may facilitate internal infections and/or cause changed behavior and performance thus inflicting data invalidity. Two days post surgery the surgically implanted fish had no or only slight signs of inflammatory reaction around the incisions. The exception was two fish, one in which the larger wound had opened, and another where it gapped at one end. These animals were instantly euthanized and data omitted from the analysis.

Ten days post surgery an inflammatory response (redness and slight swelling) was noted around all the larger incision made alongside the basibranchiale bone. These observations are in accordance with a previous study in which *G. morhua* (kept at comparable temperatures of 9.5-14° C) were surgically implanted with dummy transmitters into the body cavity via incision along linea alba .[33] In these animals inflammatory responses begun 5-7 days post surgery and subsided for 4-8 days with complete wound healing after a total of 24-34 days. Obviously, the time course of, and how to secure proper wound healing following surgical implantation demands further attention.

In summary, two days of post-surgical recovery will not stabilize GER in *G. morhua*, but ten days will, when using a standard force feeding protocol. The results indicate that at ten days post surgery the presence of a dual channel dummy telemetric implant *per se* did not affect GER but that the effects observed 2 days after instrumentation are due to surgery, post-surgical stress and/or the presence of the implant. Biotelemetry has the welfare advantages of allowing long recovery periods and avoiding the unnecessary stress arising from handling and confinement, altogether improving quality of data and we believe our results to leave a promising future for implementation of fully implantable biotelemetry systems in fish.

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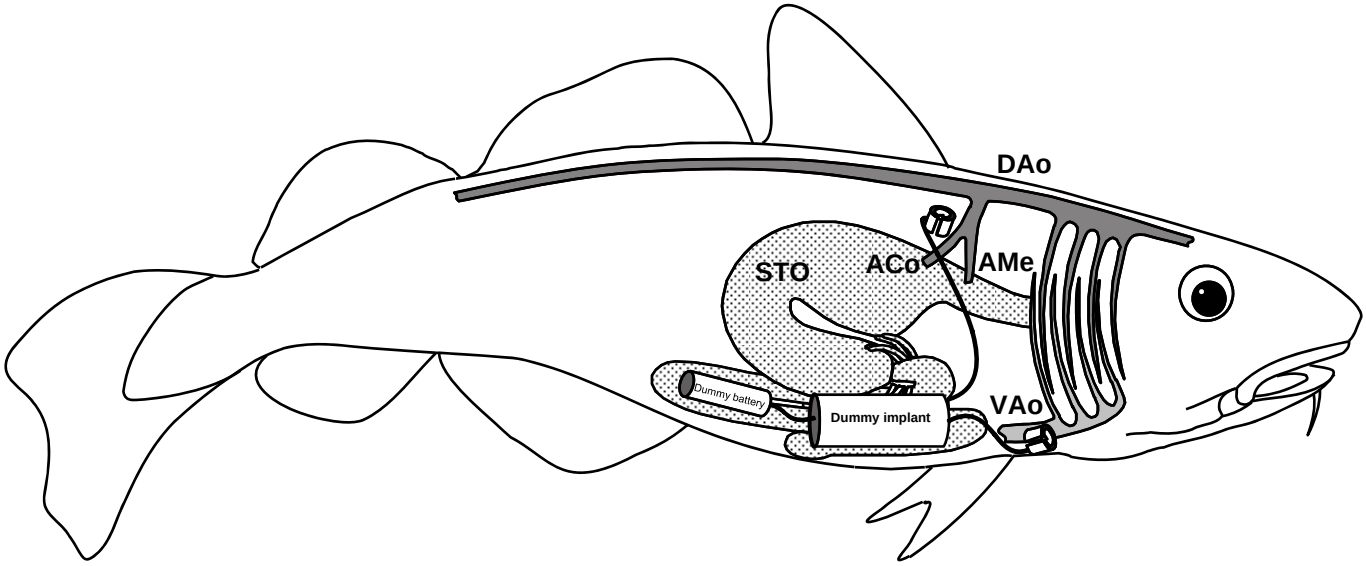
493 Figure 1.

494 Schematic drawing of a *Gadus morhua* showing the placement of the dummy implant and battery
495 (both drawn to scale) in the abdominal cavity and the flow probes belonging to it. The
496 celiacomesenteric artery branches off the dorsal aorta (DAo) and subsequently divides into the
497 celiac (ACo) and the mesenteric artery (AMe). VAo, ventral aorta; STO, stomach

498

499 Figure 2.

500 Comparison of the basic rate parameter rho (ρ_{LTE}) two and ten days post surgery for force-fed
501 surgically implanted (hatched, n=9) and control (grey, n=8) *Gadus morhua* and with estimates
502 from non-operated voluntarily feeding conspecifics (white).[1] Data are presented as mean (SD), *
503 indicates a significant difference (P<0.05) between the force-fed groups two days post surgery, †
504 indicate significant difference (P<0.05) between non-operated voluntarily feeding fish and all
505 force-feeding trials (i.e. both two and ten days post surgery).


DAo
STO
ACo
AMe
VAo
Dummy battery
Dummy implant

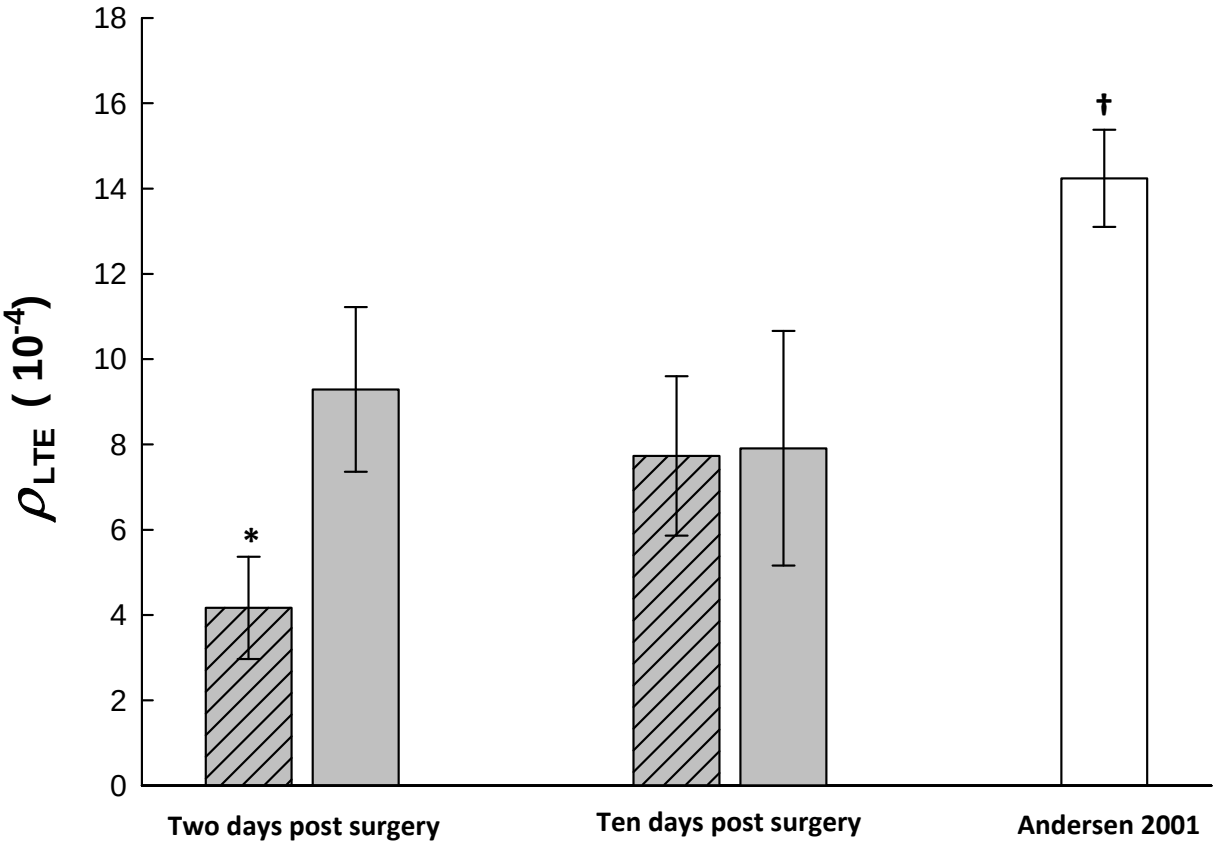

18
16
14
12
10
8
6
4
2
0
ρ_{LTE} (10^{-4})
*
†
Two days post surgery
Ten days post surgery
Andersen 2001

Table I. Basic data on gastric evacuation experiments (mean [SD]) on *Gadus morhua*. All experiments were carried out at 9-10 °C and all meals consisted of a single prey.

	Predator *Gadus morhua*			Prey *Ammodytes marinus*			
Group and experiment	*L* (cm)	Body mass (g)	Time *t* (h) for recovery of force-fed meal	Original body mass (g)	Recovered body mass at time *t*	Energy *E* (kJ g^{-1})	Observations (*n*)
Surgically implanted fish two days post surgery	38.7 (3.2)	550 (144)	25.3 (0.5)	12.9 (1.3)	10.1 (0.8)	6.83	9
Control fish two days post surgery	37.1 (2.7)	518 (155)	25.2 (1.4)	12.3 (1.8)	7.0 (0.9)	6.83	8
Surgically implanted fish ten days post surgery		545 (146)	23.6 (0.8)	12.9 (1.8)	8.2 (1.3)	6.83	9
Control fish ten days post surgery		503 (151)	23.5 (1.3)	11.5 (1.4)	7.2 (0.9)	6.83	8

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Table II. Coefficient of variation (CV) of the basic rate parameter ρ_{LTE} obtained from *Gadus morhua* fed an *Ammodytes marinus*. Different letters indicate a significant difference.

	Surgically implanted *G. morhua* (*n*=9)	Control *G. morhua* (*n*=8)	*G. morhua* feeding voluntarily on *Ammodytes tobianus* (n=20) (from Andersen[1])
Two days post surgery	0.287[a]	0.207[a]	0.080[b]
Ten days post surgery	0. 242[a]	0. 348[a]	